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CANADA
DEPARTMENT OF MINES

HON. CHARLES STEWART, MINISTER; CHARLES CAMSELL, DEPUTY MINISTER

MINES BRANCH

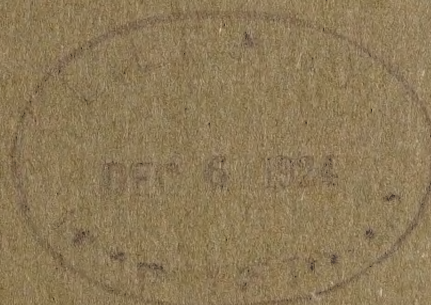
JOHN MCLEISH, DIRECTOR

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BENTONITE

BY

Hugh S. Spence



OTTAWA
F. A. ACLAND
PRINTER TO THE KING'S MOST EXCELLENT MAJESTY
1924

No. 626.

Canada. Mines, Bureau of -

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INTRODUCTORY

The clay-like material, bentonite, was first described by W. C. Knight in 1898. Attention was first drawn to the deposits in the Rock Creek district of the state of Wyoming. It was later found that the material is quite widely distributed in Wyoming, and occurs, also, in the adjoining state of North Dakota. Clays of similar composition and physical character have more recently been found in California, Nevada and Tennessee.

In Canada, bentonite has been found at a number of localities in the Prairie Provinces, and in British Columbia. References to many of these occurrences are contained in the reports of Ries and Keele.¹ More recently, the writer has made a special survey of the more important deposits, and it has been found that Canada possesses important bentonite resources that can readily be made available, should a demand for the material arise.

At the time of original discovery, considerable interest is believed to have been aroused in the industrial possibilities of bentonite, but only limited success attended attempts made to utilize the material, and little more was heard about it until recently. A few years ago, renewed efforts to turn the Wyoming bentonite to account resulted in the material engaging the more serious attention of industry, and considerable research has since been undertaken both under Government and private auspices, in an endeavour to develop uses for it. The work done has been attended with conspicuous success in several important fields of industry; and, though bentonite is not yet being utilized on a large scale, it is thought that its peculiar properties will ultimately render it of high industrial importance.

Very little information regarding bentonite has been published except brief articles contained in Government reports and scattered through technical journals—sources not always readily available to those most likely to be interested in the material. Because of the many requests for information on the subject of bentonite addressed to the Mines Branch, an attempt has been made in this report to summarize briefly the available data regarding its occurrence, distribution and possible uses. The results of work conducted in the Mines Branch Chemical Division, by E. A. Thompson and A. Sadler, upon the composition and physical character of bentonite, are also included here. The bibliography given in the Appendix will enable those interested to refer in greater detail to many of the principal sources of information used in the preparation of this paper.

The writer desires to acknowledge, with much appreciation, the assistance given him by those who, in the field or through interviews and correspondence, have contributed to the preparation of this report. Thanks are specially due to Mr. P. Prutzman, General Petroleum Company, Los Angeles, Calif.; Mr. W. A. Collings, Santa Monica, Calif.; Mr. C. F. Carey, Owyhee Chemical Products Company, Chicago, Ill.; and Dr. H. Kriegsheim, Permutit Company, New York, for information furnished; also to Mr. W. G. Worcester, Professor of Ceramics, University of Saskatchewan, for assistance in the field work, and to Dr. C. S. Ross, United States Geological Survey, Washington, for kindly preparing and examining thin sections of a number of bentonites.

¹ Clay and Shale Deposits of the Western Provinces, Memoir No. 25, Geol. Surv. Can., 1913; Memoir No. 66, Geol. Surv. Can., 1915.

BENTONITE ¹

DISTRIBUTION

Bentonite occurs as a bedded sediment in deposits ranging from a few inches to as much as 10 feet in thickness. These beds are found at different horizons throughout a considerable thickness of the Cretaceous rocks in the western portions of both the United States and Canada, but chiefly in the Upper Cretaceous, in which they occur interbedded with sands, shales, and not infrequently with lignite seams. Deposits also occur in beds of lower Tertiary age.

Bentonite was first noted and described from the Benton formation of Rock creek, Wyoming, but it has since been reported from numerous other localities in the same state and in South Dakota. Clays showing similar characteristics are also stated to occur in Florida, Tennessee and other parts of the United States.

CANADA

Bentonite occurrences have been investigated by the Mines Branch, Department of Mines, at a number of localities in Saskatchewan, Alberta, and British Columbia. It seems probable that bentonite is very widely distributed over a considerable area of the southern portions of Saskatchewan and Alberta, as well as of the adjacent states to the south. On the prairies, owing to the level terrain and the paucity of deeply cut drainage channels, good sections of the Cretaceous rocks are rare. Consequently, it is only in regions of bad land topography, such as the valley of the Red Deer river, or where the Cretaceous beds outcrop on the tops or sides of knolls, or along coulees, that the bentonite beds are visible. The sticky nature of the prairie gumbo soils is probably due to the presence in them of bentonite, derived either from bentonite beds or from bentonitic sandstones or shales, and this would suggest a wide-spread distribution of bentonitic sediments over the Prairie Provinces.

¹NOTE.—According to C. S. Ross, of the United States Geological Survey (personal communication to the author), recent microscopic and X-ray studies on bentonite indicate that it possesses crystalline rather than colloid character, and that the material probably consists, in the main, of the definite mineral *leverrierite*. The pseudo-colloidal behaviour of the clay in aqueous suspensions is regarded as due to the micaceous structure of the fine mineral particles, which are, however, for the most part, of greater than colloidal dimensions. The flake form of the particles would give them relatively enormous surface, and the penetration of water between the flakes is assumed to account for the tremendous swelling power of the clay when water is added to it.

In view of the fact, however, that the behaviour of bentonite in bentonite-water mixtures simulates closely that of true colloids, in that permanent suspensions or dispersions may be formed, the original conception of the material as colloidal clay has been adhered to in this report. The fact, also, that in the literature dealing with bentonite, the colloidal nature of the material has been assumed, makes it desirable, in order to avoid conflict of ideas, to employ the same terms. Accordingly, in the discussion of the character and properties of bentonite, the term colloidal is to be understood as referring to the peculiar property of the material that enables it to suspend or disperse in water in a similar manner to true colloids, even though the mean size of the particles that compose it is greater than that arbitrarily assigned to colloidal dispersoids.

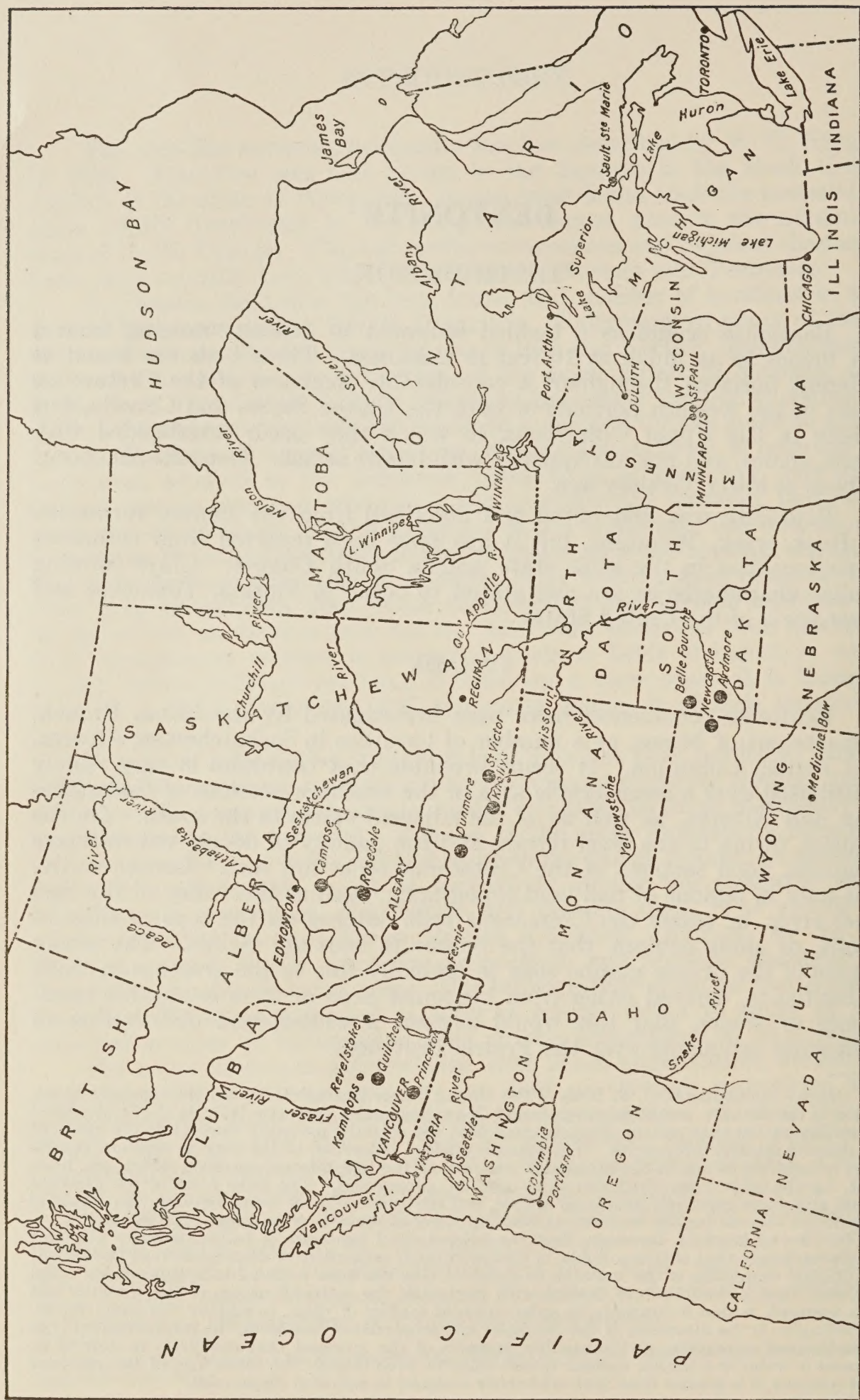


Fig.1.—Sketch map showing location of bentonite occurrences in Canada and United States.

Manitoba

In Manitoba, S. C. Ells reports¹ bentonite beds up to 24 inches in thickness on the main branch of Favel river (tp. 36, range 26, W. 1st mer.); on Ochre river (tp. 24, range 17, W. 1st mer.); and on Sclater river (tp. 34, range 23, W. 1st mer.). A. MacLean notes (G.S.C., Summ. Rep., 1914, p. 70) about 50 feet of "waxy, tenacious clay, probably consisting largely of colloidal material, very similar to bentonite," in Dead Horse valley, Pembina mountains, sec. 20, tp. 2, range 6, W. 1st mer., and in Pembina valley, from the international boundary to E. $\frac{1}{2}$ sec. 23, tp. 2, range 9, W. 1st mer.

Saskatchewan

In Saskatchewan, Ells mentions the occurrence of beds 5 to 24 inches thick, and ranging in colour from cream to shades of pink and green, on Man river (tp. 52, range 4, W. 2nd mer.); on Cracking river (tp. 50, range 7, W. 2nd mer.); and on other small streams draining north into Carrot river. In the southern part of the same province, outcrops of bentonite beds occur on both sides of the valley at St. Victor (sec. 2, tp. 6, range 29, W. 3rd mer., and sec. 14, tp. 6, range 28, W. 3rd mer.), and in the Cypress hills, near Knollys (sec. 17, tp. 6, range 22, W. 3rd mer.).

Alberta

In Alberta, beds are exposed near Camrose, and in the buttes and cliffs of the Red Deer valley at Drumheller and Rosedale, also in the workings of the Rosedale Coal Company at the latter place. An outcrop of about 18 feet of impure bentonite, containing large crystals of selenite and nodules of chalcedonic quartz, occurs 8 miles south of Dunmore (Coleridge), on sec. 14, tp. 11, range 4, W. 4th mer.

British Columbia

In British Columbia, bentonite occurs in beds of considerable thickness in the Tertiary measures, near Nicola, and at Princeton. At the latter place, a parting of bentonite is found in the coal seam in the mine of the Princeton B.C. Colliery Company, the association being similar to that in the Rosedale Coal Company's workings. Keele (Mines Branch Summ. Rep., 1918, p. 160) reports the occurrence of bentonite clays from Seventeen Mile House, on the Cariboo road, Fraser River valley, and from the mouth of Gorge creek, Deadman River valley, in the Kamloops district. Field relationships indicate that these clays are derived from glassy volcanic rocks of the dacite-andesite type. The wide-spread occurrence of such rocks in the Interior Plateau region of British Columbia suggests that important bentonite deposits may be found there.

Samples of the material from many of the above-mentioned localities, and from a number of deposits in the United States, have been secured by the Mines Branch, and it is intended to experiment upon them for the purpose of comparing their purity and colloidal character.

So far, no attempt has been made to develop any of the Canadian bentonite deposits, and no supply of the material is immediately available. This is natural, in view of the fact that there is as yet no important demand for bentonite, and such enquiries as have come to hand are mainly in the

¹ Cretaceous Shales of Manitoba and Saskatchewan, Mines Branch Memorandum Series No. 3, 1921.

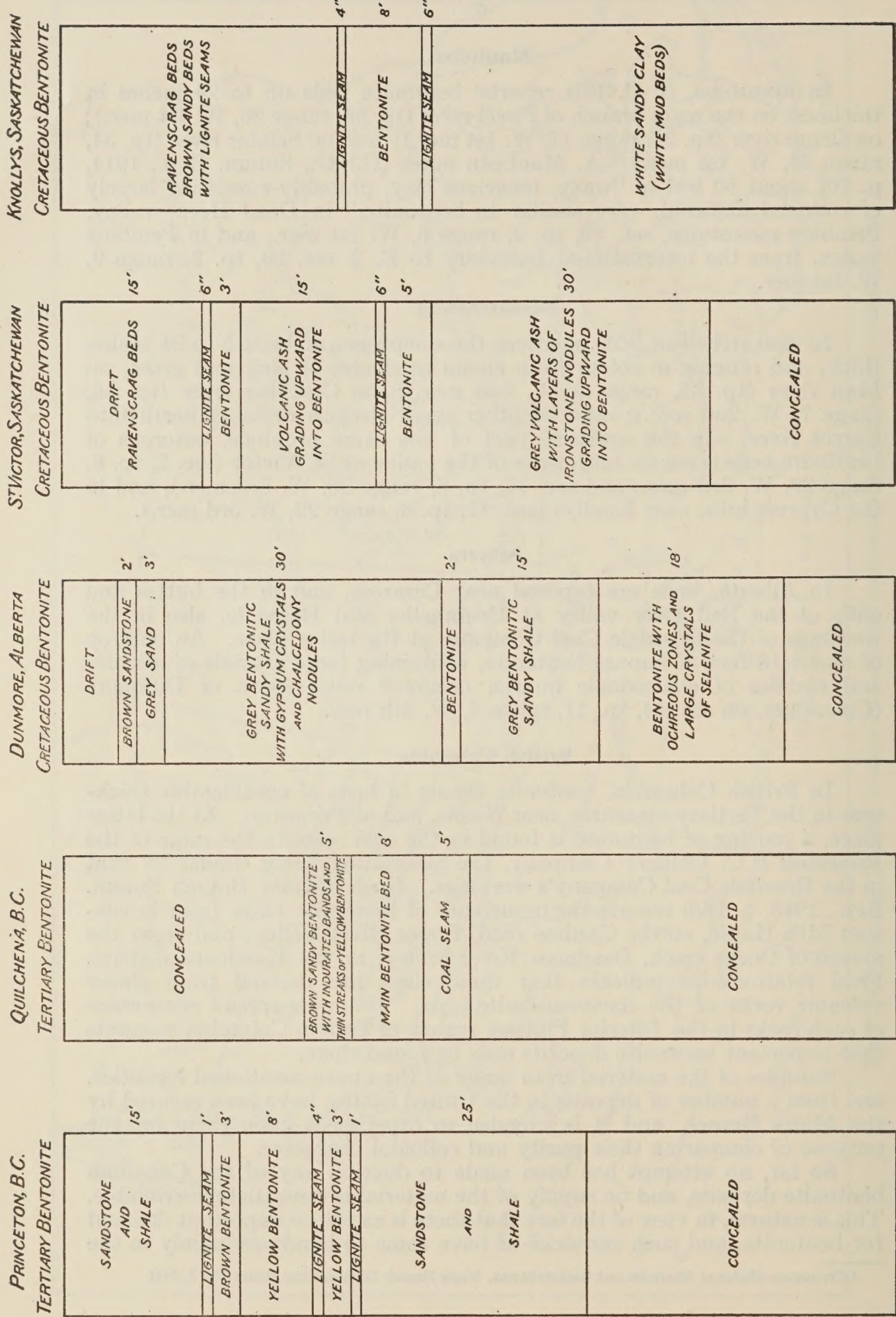


Fig. 2.—Sections showing association of bentonite beds in western Canada. At all the localities noted the bentonite is overlain by considerable overburden.

nature of requests for small amounts for experimental purposes. Owing to the lack of knowledge of the clay and its possible uses by those interested in deposits, proper care is frequently not taken in sampling, and consequently the samples are often not representative of the material available, being contaminated by sand, grit or other impurities, introduced during sampling or subsequently. For most, if not all of the purposes for which bentonite may possibly be shown to be of use, freedom from gritty impurities is highly desirable, so that too great care cannot be taken in sampling deposits.

Considering nearness to railway transportation, the deposits that show the most promise for immediate cheap development are those at Rosedale, Alberta; Knollys, Saskatchewan; and Princeton, British Columbia.

Rosedale.—At Rosedale, the bentonite seam in the workings of the Rosedale Coal Company measures 6 to 10 inches in thickness, and the material compares favourably in point of colloidalilty with the type Wyoming clay; it is, however, of not quite so good a colour and contains grit. Formerly, the system followed in mining the coal resulted in the removal of the bentonite as lump clay and a considerable tonnage of clean material went to the waste pile. Under the present method of mining, only the upper coal seam is taken down, the cutters being run in the bentonite parting. This results in the bentonite being broken into small pieces and contaminated by slack and dust. Possibly this waste could be avoided and the bentonite saved clean, but no attempt to do this is likely to be made until a favourable market for the clay is assured.

Knollys.—At Knollys (sec. 17, tp. 6, range 22, W. 3rd mer.), an 8-foot bed of bentonite is exposed in the side of Frenchman River valley, about one-half mile south of the railway. The bed may possibly be picked up at other spots along a distance of several miles up and down the valley, there being numerous cut banks exposing good sections of the Cretaceous sediments. A second bentonite bed is exposed on the other side of the valley, near Eastend, just below an adit driven recently for coal. This bed may possibly be the same as that at Knollys. The clay at both these outcrops is of a yellowish-green cast when damp, drying to a cream shade, in this respect resembling the Wyoming bentonite; its degree of colloidalilty has not yet been determined.

Princeton.—At Princeton, two quite distinct types of bentonite occur. In the coal mine of the Princeton B.C. Colliery Company, two thin bentonite beds are found. One forms a 3-inch parting in the coal, and the other an 18-inch bed between the lower coal seam and the shale floor. In each case the clay is creamy white, both in the wet and dry state, and appears similar to the Rosedale material. The management considers that it would be possible to take out this bentonite in a clean state during coal mining operations. One mile south of the above mine, two outcrops of bentonite occur, about half a mile apart: these are apparently two separate and distinct beds, though the clay in each case is slightly similar in appearance and of a light yellow colour. A short drift on one of these outcrops discloses a bed of bentonite at least 6 feet thick and having a slight dip to the south. This outcrop is half a mile from the railway, and the deposit could be easily and cheaply worked. About half a mile west of the above occurrence, a bed of bentonite about 14 feet thick outcrops in the side of

a railway cut. This bed appears to lie between two thin lignite seams and is not homogeneous throughout. The upper 3 feet consist of a brown, gritty bentonite, which gives way downward to 8 feet of yellowish-green clay containing occasional small inclusions or pockets of lignite. This is followed by a 4-inch lignite seam, under which lies another 3 feet of yellow bentonite. This occurrence, besides being the thickest Canadian bentonite deposit at present known, offers exceptional facilities for development since the clay could be loaded directly into freight cars. The Princeton B.C. Colliery Company, on whose land the outcrop occurs, quote a freight rate of \$5 per ton to Vancouver. No work has ever been done on this deposit.

UNITED STATES

Wyoming

In the United States, the most important producers of bentonite are the Owyhee Chemical Products Company, with deposits at Medicine Bow, Wyoming, and a grinding plant at Cheyenne, and the Wyoming Bentonite Company, whose mine is at Clay Spur, near Newcastle, Wyoming. The first-named company markets crude clay, coarsely ground clay, and a finely powdered product which is sold under the trade name of "wilkinite." The Wyoming Bentonite Company markets only crude bentonite. The clays from the above deposits are very similar in appearance, both being of a greenish-yellow cast when wet and drying out to a creamy white shade. In both cases, the bentonite is found as a surface outcrop, and can be easily and cheaply mined. At Clay Spur, the deposit worked is a flat-lying bed, associated with dark bentonitic shales, the whole forming a low mesa-like terrace in gently rolling country. The overburden is slight and is removed by scrapers, after which the bentonite bed is broken up by a plough and loaded into wagons. There are said to be several beds, but only one is worked. In the Medicine Bow region, beds of different thicknesses occur, but most of them are too thin to be worked profitably. The main bed worked by the Owyhee Chemical Products Company is about 5 feet thick, and is over- and underlain by Pierre shale. The beds range in dip from about 30° to nearly vertical, the series being bent into a system of synclines and anticlines. The mill process consists in drying the crude clay, crushing it down and then reducing it in a hammer mill or in an air float roller mill, according to whether a coarse or fine powder is desired.

South Dakota

In South Dakota, bentonite occurs in the Ardmore and Belle Fourche districts, in the southwestern part of the state. At Ardmore, beds of the clay have been worked quite extensively to supply material to the Refinite Company at Ardmore for the manufacture of water softeners. The clay forms a number of beds, varying from a few inches to as much as 4 feet in thickness, interbedded with dark Pierre shales. The Ardmore bentonite is of a deep grey colour when freshly broken out, but weathers to a yellowish shade. The weathered outcrops contain large masses of gypsum crystals. The Belle Fourche bentonite is of the same general character: there has been virtually no production from this district as yet, but it is reported that a company has recently been formed to develop the deposits and to erect a grinding plant.

California

At Otay, near San Diego, California, a large deposit of a clay apparently similar in a general way to bentonite, has been worked on a considerable scale for use in oil refining. The bed is flat-lying and outcrops around the north flanks of the Otay mesa. It measures about 12 feet in thickness, and is made up of several alternating layers of brown, pink and white clay, the whole being over- and underlain by heavy-bedded sands. The clay of the individual layers is similar in general character, but the brown clay is stated to be the best suited for treating oils. The material of this deposit has been variously termed "otaylite" (from Otay), montmorillonite, and bentonite; its chemical composition is quite similar to that of a number of bentonites analysed in the Mines Branch chemical laboratory, but it is, apparently, not as highly colloidal as the type Wyoming material. About 10,000 tons of the Otay clay have been mined to date, most of it for use in the oil industry.

Clays of colloidal character are reported to occur at several localities in the Sierra region of California. Between Barstow and Daggett, in San Bernardino county, a light, cream-coloured clay is mined by the Master Products Company, 5756 Alba Street, Los Angeles. According to information furnished by this company, the clay is won by underground mining, air-dried and shipped to Los Angeles for grinding. Grinding is performed in a Raymond mill, the product being air-floated. The quantity of clay mined to date (1924) is reported as 3,000 tons. The selling price of the powdered clay (200 mesh) is stated to be \$20 per ton, f.o.b. Los Angeles.

At Shoshone, in the northern part of San Bernardino county, the Associated Oil Company, of San Francisco, have mined bentonite for use in refining petroleum products. The clay is air-dried at the mine and shipped to the company's refineries at Avon, Calif., for treatment. The Filtrol Company, of Los Angeles, have also mined bentonite in the same area, shipping it to their works at Los Angeles, where it is ground in a Raymond mill and prepared for the cleaning of vegetable oils, fats, etc. Clays of similar character are also reported to occur at a number of other localities in Kern and San Bernardino counties, and also in the Rhyolite, Beatty, Tolicha and Amargosa Desert regions, Nevada.

Tennessee, Kentucky and Alabama

Recent investigation has disclosed the occurrence¹ of a bed of clay, similar in its essential characteristics to bentonite, in rocks of Ordovician age in Tennessee, Kentucky and Alabama. The bed has been traced from Birmingham, Alabama, in the south, to Perry county, Ohio, in the north, a distance of nearly 500 miles; and it is thought possibly to extend over an area 800 miles long by 450 miles wide. Near High Bridge, Kentucky, the bed is stated to measure 10 feet in thickness. This occurrence is particularly interesting, since it is believed to be the only recorded instance of bentonite occurring in rocks older than the Cretaceous.

CHARACTER, CHEMICAL COMPOSITION AND PHYSICAL CHARACTERISTICS OF BENTONITE

The material that commonly goes under the name of bentonite has been known for a number of years. It was originally styled taylorite, after William Taylor, of Rock Creek, Wyoming, who first drew attention

¹ See W. A. Nelson, Volcanic Ash in the Ordovician of Tennessee, Kentucky and Alabama, Bull. Geol. Soc. Amer., Vol. 33, 1922, pp. 605-616.

to it. Later, it was found that this name had already been allotted in mineralogical nomenclature, and the present name of bentonite was substituted, as the beds occurred in the Fort Benton series of Upper Cretaceous rocks.

Nearly all the so-called bentonites carry varying percentages of gritty impurities, and such variations are to be noted not only in the clay from different deposits but in the different portions or levels of the same bed. Disregarding such gritty or sandy material, however, and considering only the very finely divided clay substance, it is found that this varies within very wide limits in its ability to form clay-water suspensions. Some deposits yield a bentonite, a large proportion of which disperses readily in water and gives an almost permanent suspension; the material of other deposits gives only a comparatively small amount of suspension, while some give none at all, although the raw clay is to all appearance identical and is found in beds of similar age. Furthermore, such differences are reported to have been observed even in the material of a single deposit. One cause of these differences is very probably the presence in the clay of soluble salts, which, on the addition of water, form electrolytes that flocculate the clay particles. The electrolytes that come into question most commonly are sodium sulphate, alum or even weak sulphuric acid, formed by the decomposition of the detrital rock-forming minerals present either in the original clay itself or in the beds of shales or sands associated with it. The natural moisture content of the clay may be an alternative or contributory cause of variation in the colloidal behaviour of bentonites from different districts. Pronounced desiccation of clay gels seems to result in conversion of the colloidal matter to the amorphous condition, in which state re-hydration (corresponding to reversion to the colloidal condition) proceeds with difficulty. Prolonged agitation of bentonite-water mixtures, yielding at first only slight suspensions, often results in progressively larger amounts of the clay becoming dispersed as the time of agitation is increased. The increased plasticity of clays subjected to artificial ageing is thought to be similarly due to progressive hydration of the sub-microscopic particles.

As a natural corollary of the above, it might be expected that material from the surface outcrop of a bentonite bed would exhibit higher colloidalities than that from deeper seated portions of the same bed. This remains to be demonstrated, however, since very few deposits have been worked to any appreciable depth. It may be stated that such is not the case with the bentonite from a dry coal mine at Rosedale, Alberta, for although the clay was quite dry when taken out, it was highly colloidal. Again, some surface bentonites yielded hardly any suspension, but the presence in these of considerable amounts of soluble salts was often sufficiently obvious to pre-indicate the formation of flocculating electrolytes in the solution. Such bentonites may often be dispersed by the addition of peptizing reagents, such as sodium hydroxide, to the clay-water mixtures; these having the effect of increasing the hydrogen-ion concentration of the liquid and thus promoting deflocculation of the clay. The conditions attending the original deposition of the clay, however, have to be taken into account here, more particularly with respect to the presence of soluble salts in the clay, since it is conceivable that the amount of such salts will depend on the degree of leaching that took place during and since deposition, and the ease with which they could be carried away by drainage

waters. In general, it is very difficult to remove adsorbed salts from clay gels by washing.

The possible factors noted above that may influence the character of bentonite are worth keeping in view in sampling bentonite deposits and in determining the colloidal behaviour of the material, since it is at least possible that surface clay will differ considerably, in point of higher dispersibility, from clay at depth—an important point, when it comes to developing a property.

Analyses of crude bentonite show that it is composed essentially of silica, alumina and water, which make up approximately 90 per cent of the material, in the ratio (mean of 15 analyses) of 61 : 18 : 10. The remaining constituents are chiefly iron, magnesia, lime and the alkalies. In this connection, it is interesting to note that analyses conducted by A. Sadler, of the Mines Branch, showed that the composition of the suspended material from 24-hour suspensions of bentonite in water approximated very closely to the above figures for crude bentonite, the mean of 8 analyses showing ratios of 58 : 19 : 12 for silica, alumina and water, respectively. This uniformity in chemical composition of the crude clay and its suspensions is significant in considering the origin of bentonite.

Although the chemical composition of bentonite may be readily determined by analysis, some doubt has existed as to the manner in which the main constituents, silica, alumina and water, are combined, or to whether the two first-named are indeed combined at all. Determination of the relative percentages of these components present in the clay, has still failed to show whether or not bentonite is a definite mineral compound (a hydrous silicate of alumina, on the order of the kaolin molecule) or hydrous (colloidal) silica and hydrous (colloidal) alumina in indefinite and variable proportions. E. S. Larsen,¹ who has studied bentonites from a number of different localities, is of the opinion that the material is composed mainly of the definite mineral leverrierite, which has the composition $2\text{Al}_2\text{O}_3 \cdot 5\text{SiO}_2 \cdot 5\text{H}_2\text{O}$ and crystallizes in the orthorhombic system (C. Doelter, *Handbuch der Mineral Chemie*, vol. 2, Pt. 2, 1917, p. 142). X-ray crystallographic studies upon bentonite by R. Wyckoff, of the Geophysical Laboratory, Washington; as well as investigations by H. E. Merwin, also of the Geophysical Laboratory; W. F. Foshag and E. V. Shannon, of the United States National Museum; and W. T. Schaller and C. S. Ross, of the United States Geological Survey, bear out the crystalline nature of bentonite and indicate its definite mineral character.²

Investigation of the iso-electric point of bentonite-water suspensions, and determination of their hydrogen-ion concentration, might throw additional light on the true character of bentonite. Failure to establish a sharp iso-electric point would suggest that the material is a mixture of colloids (silica, alumina, etc.), while a definite iso-electric would indicate a single colloidal substance.

Full chemical analyses of a number of bentonites have been conducted by A. Sadler, of the Mines Branch, and are given in the following table. It is to be clearly understood that the material analysed in each case was the crude clay and thus included the grit as well as the actual clay substance. All the clays had been dried at room temperature for a period of some months at least.

¹ Personal communication, 1924.

² Personal communication from C. S. Ross, 1924.

Analyses of Crude Bentonites

	1	2	3	4	5	6	7	8	9	10	11
Silica.....	69.70	67.04	69.60	68.78	68.60	54.88	59.80	60.78	66.90	53.90	61.94
Alumina.....	14.00	13.46	11.84	13.10	12.10	19.92	16.36	17.08	15.26	18.00	15.97
Ferric oxide.....	2.88	2.79	1.79	2.48	2.00	4.10	2.23	3.67	2.80	3.21	2.92
Ferrous oxide.....	0.23	0.23	0.22	0.22	0.32	0.22	3.52	0.43	0.12	0.18	0.71
Lime.....	1.56	1.78	2.28	1.87	1.84	2.22	1.82	2.84	0.46	1.00	1.72
Magnesia.....	1.81	1.93	1.75	1.83	1.84	2.83	2.67	2.16	2.26	3.61	2.45
Titanium oxide.....	0.23	0.25	0.20	0.22	0.14	0.25	0.05	0.22	0.11	0.65	0.23
Phosphoric acid.....	0.01	0.09	0.09	0.06	0.17	0.09	trace	9.03	0.04	0.10	0.07
Soda.....	1.09	0.53	0.49	0.70	0.50	1.75	2.00	1.54	2.12	2.72	1.61
Potash.....	0.29	0.22	0.14	0.21	0.23	0.26	0.27	0.46	0.42	0.21	0.29
Sulphur.....	0.02	0.01	nil	0.01	nil	nil	nil	0.04	0.01	nil	0.01
Sulphuric acid.....	nil	nil	nil	nil	0.61	0.16	nil	0.01	0.08	0.19	0.15
Carbon dioxide.....	0.04	0.02	0.73	0.26	0.17	0.37	0.72	1.11	0.05	0.21	0.41
Carbon.....	0.09	0.10	0.07	0.08	0.08	0.07	0.09	0.13	0.03	0.53	0.14
Water at 195° C.....	3.92	6.64	6.09	5.55	7.71	8.10	5.18	5.94	5.80	11.91	7.17
Water above 105° C.....	4.28	4.92	4.73	4.64	3.24	4.28	4.91	3.70	3.67	3.24	3.95
Total.....	100.15	100.01	100.01	100.01	99.55	99.50	99.62	100.14	100.13	99.66	99.74

1. Quilchena, near Merritt, British Columbia. Upper 3 feet.
2. " " " Middle 3 feet.
3. " " " Lower 3 feet.
4. Average of 1, 2 and 3.
5. Princeton, British Columbia.
6. Rosedale, Alberta. Sample from a surface outcrop.
7. Rosedale, Alberta. Rosedale Coal Company's mine.
8. Camrose, Alberta.
9. Wyoming (probably Newcastle district).
10. So-called wilkinite = powdered bentonite from Medicine Bow, Wyoming.
11. Average of 4 to 10, inclusive.

For comparison purposes, the following further analyses of bentonites are given in the table below. The figures are taken from U.S. Bureau of Mines, Reports of Investigations No. 2289, 1921, entitled Bentonite, by R. B. Ladoo. Samples of certain of the clays listed here have been obtained by the Mines Branch. Sample No. 3 (so-called "Death Valley" clay), appears to be only slightly colloidal, and seems to be more of the nature of a kaolin. Sample No. 8, so-called "ardmorite," is a dark-coloured plastic clay, differing rather in appearance from typical bentonite; this clay is used as raw material in the manufacture of a well-known water softener (Refinite).

Analyses of Crude Bentonite

	1	2	3	4	5	6	7	8
Silica.....	60.64	57.98	58.68	59.84	60.18	63.20	54.00	55.22
Alumina.....	23.26	22.46	25.91	11.84	26.58	12.90	24.48	21.00
Ferric oxide.....	3.92	3.80	3.97	3.26	.....	2.46	3.00	3.61
Titanium oxide.....	0.12	.....	.....	.....	.....	0.11	.....	.....
Lime.....	0.59	1.92	1.45	2.90	0.23	0.82	2.08	4.94
Magnesia.....	2.19	3.24	1.49	2.32	1.01	2.09	2.75	3.04
Potash.....	0.37	1.35	.....	2.31	1.23	0.26	.....	.....
Soda.....	4.33	.....	1.39	2.13	.....	0.66	1.74	1.56
Sulphuric anhydride.....	.....	0.75	0.11	.....	.....	.....	.....	0.43
Carbon dioxide.....	.....	.....	trace	.....	.....	3.50	.....	trace
Chlorine.....	.....	.....	0.10	.....	.....	0.20	.....	.....
Phosphoric acid.....	.....	.....	0.06	.....	.....	.....	0.71	.....
Loss on ignition.....	.....	7.93	.....	10.50	.....	.....	.....	.....
Water.....	2.83	.....	6.84	.....	10.26	13.80	9.12	10.28
Total.....	98.25	99.43	100.00	95.13	99.49	100.00	97.88	100.08

1. Yellow colloidal; Belle Fourche, South Dakota.
2. Yellow colloidal; Medicine Bow, Wyoming.
3. White, colloidal; near Barstow, California.
4. White, fine-grained; Otay, San Diego county, California.
5. Type material, Rock creek, Wyoming.
6. Big Horn basin, Wyoming.
7. Supposed bentonite; near Shelbyville, Tennessee.
8. So-called "ardmorite"; Ardmore, South Dakota.

The bentonites of the western United States and Canada are characterized in the field by their exceedingly sticky nature when wet. The great majority of ordinary clays exhibit plastic qualities in some degree, but bentonite may be termed "hyper-plastic"; that is, it does not possess working qualities even when mixed with the minimum amount of water necessary to thoroughly wet it, but passes at once from the "short" state to a sticky, unworkable condition. Bentonite is so impervious, however, that rain water does not penetrate very far into the beds, and even where the clay is exposed to the weather only the top few inches ever become wetted by atmospheric moisture.

Bentonite outcrops always exhibit very characteristic weathered surfaces, having a crinkled, coral-like appearance, due to the alternate swelling and shrinkage of the material upon repeated wetting and drying out. The observer cannot fail to notice at once the unusual appearance of a bentonite exposure, especially as little or no vegetation will grow upon the clay, and consequently barren weathered outcrops are conspicuous features of prairie lands.

Bentonite, broken out from beneath the wet surface crust, often exhibits a characteristic sub-conchoidal fracture and is frequently quite hard and brittle. Some of the Wyoming material, on the other hand, exhibits a laminated or shaly structure. Most bentonites, when dry, are powdery or earthy to the touch, but the so-called otaylite, from California, has a distinctly greasy feel.

Bentonites are commonly light in colour ranging from cream to olive green, but in some cases they are coloured darker by carbonaceous material. Most bentonites become darker on wetting; many of the samples taken wet in the field, and in that state of a dark olive green colour, dried out in the air to a light cream shade. Some of the lightest coloured bentonites seen were associated directly with coal seams. The bed in the Princeton B.C. Colliery Company's mine, Princeton, B.C., was the nearest approach to white of any examined, but, contrary to the general rule, this clay darkens on drying to a creamy-buff colour. The so-called otaylite from California is variously buff, chocolate brown or pink, depending on the horizon from which it is taken. No pure white bentonites, comparable in colour to high grade china clay, have come to the writer's attention.

It has been noted that prolonged air-drying of bentonite seems to result in a decrease in dispersibility. This phenomenon is probably closely allied with the well-known property of clays in general to become more plastic ("fat") after being subjected to weathering for a considerable period; the artificial ageing or "souring" of clays effects the same purpose, probably by favouring hydration of the particles. This characteristic is an inherent one of clays, and is due to the inability of completely desiccated clay particles to re-absorb their full capacity of water, except very slowly. The use of a suitable electrolyte hastens the rehydration process, and it has been shown that some bentonites, which exhibit low dispersibility

may be readily dispersed by such means. This indicates, as pointed out elsewhere in this paper, that to ensure a uniform clay that will be acceptable to industry at large, treatment of the raw bentonite will be a prerequisite, and that little progress is to be expected from attempts to market the crude material.

The following physical properties of certain bentonites (crude clay in each case) have been determined by E. A. Thompson of the Mines Branch Chemical Division.

Water absorption. One gramme of each of the named samples was found to absorb the indicated number of grammes of water:—

	grammes
Quilchena, British Columbia.....	1.53
Camrose, Alberta.....	4.15
Rosedale, Alberta.....	4.71
Newcastle, Wyoming.....	4.93
Medicine Bow, Wyoming (wilkinite).....	4.95

When at full saturation, the increase in volume of the above samples ranged from five to thirteen times the dry bulk.

Specific gravity. Determined by pycnometer on clay dried at 105° C. for two hours:—

Quilchena, British Columbia.....	2.44
Camrose, Alberta.....	2.73
Rosedale, Alberta.....	2.72
Newcastle, Wyoming.....	2.77
Medicine Bow, Wyoming (wilkinite).....	2.78

Fusion point. Determinations made by means of Seger cones:—

	Cone	Temperature
Quilchena, British Columbia.....	15	1430° C.
Rosedale, Alberta.....	14	1410° C.
Newcastle, Wyoming.....	11	1350° C.
Medicine Bow, Wyoming (wilkinite).....	10	1330° C.

Refractive index.—

	Index
Quilchena, British Columbia... ..	1.547
Rosedale, Alberta.....	1.558
Newcastle, Wyoming.....	1.557

Effect of heating. When the clay is heated, there is a marked decline in its colloidal and distention properties. Moisture determinations were made after heating the clay to the temperatures shown below, but at even the highest temperatures used, water of combination was still retained, although colloidal behaviour was destroyed. A different temperature was required to destroy the swelling property in the case of the different samples:—

	Moisture content of air dry clay	Moisture content after heating to				
		450° C.	500° C.	550° C.	600° C.	700° C.
	per cent	per cent	per cent	per cent	per cent	per cent
Quilchena, British Columbia.....	4.64	*4.04	3.94	.....	2.53	1.50
Camrose, Alberta	3.70	.....	*3.60	.....	2.09	1.14
Rosedale, Alberta.....	4.28	.....	.....	*4.17	.....	.....
Newcastle, Wyoming... ..	3.67	.....	3.49	.....	*3.43	0.77

*Swelling property completely destroyed.

Interesting results were obtained in determining the amount of clay suspension yielded by certain bentonites. Although the conduct of the tests was not sufficiently uniform throughout to yield strictly comparable results, the latter are of interest as showing the variations exhibited by different bentonites in water suspensions of like concentration and by different concentrations of suspensions of a single bentonite.

1. Ten grammes of crude bentonite from each of the localities listed were placed in 350 c.c. of water, and agitated for 3 hours. The mixture was then screened through a 200 mesh screen, the oversize washed with 150 c.c. of water, dried and weighed. The percentage of such oversize, or grit fraction, is given in column 1 of the following table. The solution which passed the screen was allowed to stand for 24 hours and then decanted. The settled clay was then dried and weighed, the percentage being given in column 2. The percentage of dispersed clay, which for the purpose of the test was regarded as the colloidal fraction, was obtained by difference. The figures show the wide variation in colloidal character of bentonites from different sources.

	+200 mesh	Settled clay	Dispersed clay
	per cent	per cent	per cent
Quilchena, British Columbia.....	2.18	76.72	21.10
Rosedale, Alberta.....	1.58	10.10	88.32
Camrose, Alberta..	3.16	13.14	83.70
Newcastle, Wyoming.....	0.95	29.75	69.30
Medicine Bow, Wyoming (wilkinite).....	1.21	11.59	87.20

2. To determine how the degree of dilution of a bentonite-water suspension, and the time of standing, affected results, four 10-gramme samples of crude Rosedale clay were agitated with 350 c.c. of water until disintegration was complete. The solutions were then made up to 500 c.c., 1,000 c.c., 1,500 c.c., and 2,000 c.c., respectively, and the amount of clay still in suspension determined after 1, 4, 6 and 10 days.

	Clay in suspension after			
	1 day	4 days	6 days	10 days
	per cent	per cent	per cent	per cent
500 c.c. dilution....	88.46	87.25	87.25	60.72
1,000 " ".....	86.52	74.05	63.40	56.70
1,500 " ".....	85.41	71.25	58.30	48.50
2,000 " ".....	83.26	60.11	55.00	42.50

The effect of still greater dilution and time was then tried on the same (Rosedale) bentonite. Five 10-gramme samples were agitated with 350 c.c. of water and the solutions made up, respectively, to 1, 2, 3, 4 and 5 litres. These solutions were allowed to stand for 4 months, when the amount of suspended clay was determined:—

	Clay in suspension after four months
	per cent
1 litre dilution.....	33.60
2 litres "	34.40
3 " "	29.60
4 " "	27.60
5 " "	25.10

The figures in the preceding tables indicate clearly how degree of dilution and time affect bentonite-water suspensions, and show how important it therefore is, in conducting comparative dispersion tests upon bentonites, to employ a constant degree of dilution and a constant time factor, in order to get comparable results. Thorough agitation of the clay-water mixture is also important in this connection. Temperature control, also, is probably equally desirable; but no determinations of the effect of temperature of the water upon the dispersion were undertaken.

In the following table is shown the coagulating or flocculating effect of a number of reagents (mostly electrolytes) upon bentonite-water suspensions. Three different bentonites were used in these tests, the samples being from Quilchena, British Columbia; Rosedale, Alberta; and Newcastle, Wyoming. It is to be noted that the amount of clay taken in column 1 is five times as great as in columns 2 and 3, so that the figures form no basis for strict comparison between the Quilchena clay and the other two samples. The Rosedale and Newcastle clays may, however, be compared.

The tests were conducted as follows. Twenty-five 2-gramme samples each of the Rosedale and Newcastle clays, and 10-gramme samples of the Quilchena clay, were agitated with 300 c.c. of water for 3 hours. Each sample was then washed into a graduated, stoppered glass cylinder and made up to 500 c.c., the cylinders being numbered from 1 to 25. The reagent was then added, the number on the cylinder representing the amount of reagent, in c.c. The cylinders were then shaken thoroughly, and the solutions allowed to stand for 24 hours. The amount of flocculent precipitate was then read off, as shown in the table. The figure given is the constant found; that is, it is the smallest *bulk* of settled clay produced by *any quantity* of the reagent in question after 24 hours standing. In other words, the number of c.c. of reagent given in the first column is the maximum required to effect flocculation of all the clay present; incipient coagulation commenced a few c.c. below this constant.

In a general way, the number of c.c. of electrolyte given in the table may be taken as an index of the iso-electric points (maximum rate of settling) of the clay-water-electrolyte suspensions. It is to be understood, however, that the results obtained hold only for the particular procedure followed in making up the suspensions, and that comparable figures are only to be expected by duplicating this procedure under similar conditions. In other words, the hydrogen-ion concentration necessary to effect maximum settling will be found to vary within limits with the procedure followed in making the tests.

It is recognized that a number of factors combine to modify the results obtained; among these being temperature of the suspension, order of addition of clay and electrolyte to the water, degree of dilution, and time of agitation and settling. The amount of adsorbed salts present is regarded as being largely responsible for the variation in the amount of a given electrolyte required to effect complete coagulation of the Rosedale and Newcastle bentonites, respectively. Any interaction between such electrolyte and adsorbed salts will naturally affect the amount of reagent required. In the case of acids, chemical action of the acid on particles of carbonate in the grit fraction, with resultant removal of active acid and formation of other less active electrolytes (salts), must also be taken into account.

The figures in the table illustrate the well known fact that valence of the metal ion is a measure of the flocculating power of electrolytes, those of higher valence being the most active. In general, it is held that the coagulating or flocculating power of an electrolyte upon clay suspensions is a function of the hydrogen ion concentration (degree of acidity) induced by it in the solution. It appears that the hydrogen ion is a flocculator, while the hydroxyl ion is a deflocculator.

It is not possible in this general paper to enter into any critical discussion of the behaviour of bentonite-water suspensions with electrolytes; and the above brief notes are given merely to indicate the general principles governing the phenomena involved, and thus to facilitate interpretation of the results given in the table.

For further information on this subject, the reader is referred to the publications of the American Ceramic Society, the Faraday Society, and the United States Bureau of Standards which are listed in the Bibliography on pages 32-35.

Coagulating Effect of Various Reagents upon Bentonite-Water Suspensions

Reagent	Quilchena, British Columbia		Rosedale, Alberta		Newcastle, Wyoming	
	10 grammes bentonite 500 c.c. water		2 grammes bentonite 500 c.c. water		2 grammes bentonite 500 c.c. water	
	Reagent	Pre-cipitate	Reagent	Pre-cipitate	Reagent	Pre-cipitate
	c.c.	c.c.	c.c.	c.c.	c.c.	c.c.
Chlorides—						
Hydrochloric acid.....	4	200	10	225	4	175
Sodium chloride.....	17	200	19	275	18	215
Ammonium chloride.....	14	225	19	250	19	475
Barium chloride.....	4	165	9	200	14	185
Calcium chloride.....	7	175	5	200	10	180
Aluminium chloride.....	2	200	3	215	4	225
Nitrates—						
Nitric acid.....	4	195	3	275	4	225
Potassium nitrate.....	11	200	15	225	10	375
Ammonium nitrate.....	12	200	19	220	19	485
Barium nitrate.....	5	200	3	200	4	200
Aluminium nitrate.....	3	220	2	215	4	225
Sulphates—						
Sulphuric acid.....	3	175	3	175	5	125
Sodium sulphate.....	13	200	19	435	18	180
Ammonium sulphate.....	11	230	19	260	30	275
Aluminium sulphate.....	5	175	4	200	12	175

Coagulating Effect of Various Reagents upon Bentonite-Water Suspensions—*Con.*

Reagent	Quilchena, British Columbia		Rosedale, Alberta		Newcastle, Wyoming	
	10 grammes bentonite 500 c.c. water		2 grammes bentonite 500 c.c. water		2 grammes bentonite 500 c.c. water	
	Reagent	Pre- cipitate	Reagent	Pre- cipitate	Reagent	Pre- cipitate
Sulphates—						
Calcium sulphate.....	No coagulation up to 50 c.c.		No coagulation up to 50 c.c.		35	230
Hydroxides—						
Calcium hydroxide.....	"		"		36	185
Sodium hydroxide.....	"		14	285	28	380
Ammonium hydroxide.....	No coagulation up to 100 c.c.		No coagulation up to 100 c.c.		No coagulation up to 50 c.c.	
Carbonates—						
Ammonium carbonate.....	20 | 225		40 | 210		20	215
Sodium carbonate.....	No coagulation up to 100 c.c.		14 | 300		25	230
Carbon dioxide.....	No coagulation		No coagulation		No coagulation	
Sodium oxalate.....	No coagulation up to 40 c.c.		No coagulation up to 50 c.c.		30	300
Calcium oxide.....	grammes 0.3	150	grammes 0.5	225	grammes 0.3	200

All reagents half normal, except hydrochloric, sulphuric and nitric acids, which were normal. Calcium hydroxide and calcium sulphate, saturated solutions. Ammonium hydroxide, 0.90 specific gravity.

ORIGIN OF BENTONITE

The United States Geological Survey has defined bentonite as "a transported, stratified clay, formed by the alteration of volcanic ash, shortly after deposition." The bentonite beds of the west are very obviously sediments, and the clay is undoubtedly an alteration product, but it does not appear certain in many cases that the clay is what is usually understood by a transported clay: field relations indicate that it may often, just as likely, be a residual clay formed in place from transported, stratified mineral particles. That the original mineral substance was volcanic ash (very fine particles of mineral glass or pumice ejected from a volcano), probably wind-borne to its present situation, seems established.

The cause of the alteration of such ash to its present state as bentonite is thought to be hydration of the exceedingly fine glass particles, the ash having probably fallen as a dust shower into bodies of shallow water. As hydration proceeded, the clay particles became dispersed as a suspension in the water. Finally, coagulation or flocculation of the dispersed clay, with attendant settling or precipitation, was probably effected through the agency of an electrolyte. The flocculating effect of electrolytes upon clay suspensions is indicated in the above table in which are shown the optimum amounts required to effect maximum coagulation. Such conditions for the formation of bentonite from glassy mineral matter (volcanic ash), and the deposition of such clay as bedded sediments, may well have existed in Cretaceous or Tertiary times in those districts where we now find bentonite deposits. Observed field relationships also indicate that the volcanic ash theory of origin for bentonite is the most reasonable so far advanced.

Thin sections of bentonite¹ under the microscope exhibit the typical structure of devitrified glassy tuff, and show the material to be largely made up of an aggregate of micaceous plates of a secondary clay-like mineral, probably of the leverrierite group.

A common feature of bentonite deposits, is the presence nearby of alkaline salts—notably sodium sulphate. A scum of such salts is generally noticed around bentonite outcrops, more particularly near those occurring on a level terrain not traversed by drainage channels which would afford the salts an opportunity of being carried away by surface waters. Gypsum (calcium sulphate), too, is conspicuously present in some Canadian bentonite deposits. The fact that important deposits of sodium sulphate occur in western Canada suggests that this salt may have been leached from beds of volcanic ash during the conversion of the latter to bentonite, being then carried in solution by surface waters into lakes or basins where it crystallized from concentrated brine. It is significant in this connection that bentonites usually contain relatively important amounts of soda, a common content being one to two per cent Na_2O . This soda is not always readily detected, since in some cases it cannot be removed from the clay even by boiling in water. It is regarded as being adsorbed by the clay particles, and it is worthy of note that the most highly colloidal bentonites are found, on analysis, to contain the highest percentage of soda.

POSSIBLE USES OF BENTONITE

Thus far, the established field of usefulness for bentonite in industry and the arts is a limited one, and progress in developing new uses for the material has been slow, for several reasons.

In the first place, high freight charges are inevitable, since the known deposits are situated at a considerable distance from the important industrial centres. This acts as a deterrent to industries that might contemplate the possibility of using the material, and more often than not kills at the outset any suggestion of research upon it.

Most crude bentonite contains considerable amounts of impurities in the form of sand, gypsum needles or crystals, carbonaceous matter, etc., that make it necessary to refine the clay before it is suitable for the majority of uses. The colloidal character of bentonite, however, renders it difficult to clean the clay satisfactorily or cheaply. The impurities can hardly be removed by any system of dry refining, and the clay must therefore be treated by a washing process. Although this presents no actual difficulty, it is expensive, owing to the excessive amount of water absorbed by the clay and the consequent cost of drying. The use of a medium other than water—such as alcohol, acetone or gasoline—can overcome this difficulty in the laboratory, but these could hardly be employed in commercial practice. The observed variation, also, in the colloidal properties and colour exhibited by bentonites from different localities, and even from different sections of the same deposit, tends to create prejudice, as indicating that no uniformity in character can be expected. It would seem that only by attaining a thoroughly clean and homogeneous product, uniformly colloidal in its properties, is interest likely to be sufficiently attracted to the possibilities of bentonite to encourage research upon it.

¹ Personal communication from C. S. Ross, of the United States Geological Survey, who kindly prepared thin sections of a number of Canadian bentonites and made the microscopic determinations.

In other words, a product of the required purity will have to be placed on the market before any important demand is likely to be evidenced. This entails the expenditure of considerable capital upon a venture of, perhaps, a speculative nature. Until such expenditure is made, however, progress in the field of utilization of bentonite will necessarily be slow.

It may be advisable here to sound a note of warning to the prospector or others who may conclude that what is said here justifies the immediate expenditure of time and money in prospecting for bentonite deposits. Only a very small market for the clay at present exists, which the present known deposits are more than adequate to supply. The situation likely to be created by the indiscriminate staking of bentonite lands is calculated to injure any future that the clay may possess, rather than to bring profit to the individuals concerned. This is believed to have happened twenty-five years ago, when the Wyoming deposits were first brought to public notice, and extravagant propaganda only served to discredit the material. Today, research is more organized, and the broadening of the industrial field offers greater possibilities; but, even so, progress in development of uses for bentonite must almost inevitably be slow. At the present time, it is believed that only one concern manufactures prepared bentonite as a product which is made under strict mill and laboratory control. The reports of this company indicate that an increasing interest is being manifested in the possibilities of bentonite, but that the quantity demand for the prepared clay is still small.

It may be stated here that in 1921, the Mines Branch, at the request of the Imperial authorities, arranged for the shipment of five tons of bentonite from Rosedale, Alberta, to the Department of Scientific and Industrial Research, in London. This body, in conjunction with the Imperial Mineral Resources Bureau, undertook to distribute the clay to a number of industries and Research Associations in Great Britain, that were interested in the material, and also instituted special research upon bentonite in order to determine the most promising fields of usefulness. The writer, in 1922, made a survey of most of the industries that had received samples of the clay, in an attempt to ascertain what progress had been made. The result of this survey was not very encouraging, and only in a few instances was any particular interest shown in the material. Although this was disappointing, it was recognized that it was only to be expected, for the reasons given above.

The frequent requests addressed to the Mines Branch for samples of bentonite and for information regarding the material, indicate an interest in the clay that it is hoped will lead ultimately to some tangible results. The Branch has on hand a quantity of the Rosedale bentonite, as well as smaller amounts from other localities; and persons interested in the material may obtain samples by application to the Director, Mines Branch, Ottawa.

In the following pages some of the more important fields of possible usefulness for bentonite are listed. Many of these are merely uses that have suggested themselves from a study of the physical characteristics of the material, but they are given in the hope that they may prove suggestive to industrial chemists and others interested in a product of such nature.

As an Adsorbent

The adsorptive properties of bentonite for water, salts and other substances are discussed under Dewatering, Dyes, Explosives, Fertilizers, Fillers, Refining of Oils, etc. Its adsorptive power for gases does not appear to have been investigated but seems worthy of research. Artificial colloidal silica possesses high value and commercial possibilities in this connection, and bentonite suggests itself for the same purpose.

Cements and Plasters

The possibility of bentonite proving of value in gypsum and lime plasters, cements, etc., may be mentioned, though it is not known that any important use has yet been made of the material for such purposes. Tests carried out with Portland cement mixes, made up with the addition of very small amounts of bentonite (up to 1 per cent by weight), indicate that the bentonite is useful in increasing the mechanical strength of the set material and seemed to cause quicker setting.

It is stated that bentonite acts as a retarding agent in gypsum plasters.

Ceramics

The result of work done in the Ceramic Division of the Mines Branch has shown that bentonite can be used to advantage as a suspending agent in pottery glazes.

It has been shown that the addition of bentonite to enamel mixtures in the metal enamelling (agate ware) industry, results in creating improved suspension of the frit ingredients. Both in the ground coat for dry process work and in wet enamels on steel, the use of bentonite has given very satisfactory results in improving suspension and in cutting down the amount of clay required to obtain a given volume of enamel.

It has been suggested that the addition of a small amount of bentonite to mixtures for graphite crucible bodies would improve the crucibles, by effecting a closer bond between the graphite particles and the other ingredients. It is not known that any practical experiments have been carried out to test this question.

As a means of cutting down the amount of bonding clay used in electrical and chemical porcelain, abrasive wheels, etc., the use of bentonite has been proposed.

It has been shown that the addition of a small percentage of bentonite to short ceramic bodies renders them plastic, and interest is being shown in the use of bentonite as a plasticizing agent.

Most of the bentonites examined burn to a buff or light red. After heating to red heat in an ordinary Bunsen flame, fragments of crude clay proved hard enough to scratch glass.

As a De-watering Agent

Owing to its high absorptive power and affinity for water, bentonite is most useful as a de-watering agent. It suggests itself particularly, as a means of removing water from petroleum, gasoline and oils of various kinds, as well as from air and gases. In the latter connection, it might be of service as a desiccating agent in laboratory work.

Dye Industry

The great capacity shown by bentonite for adsorbing chemical salts and compounds, particularly dyes, suggests that it may have extended possibilities in the dye and colour industries. Both as a mordant, and as a base for lake colours, its high adsorptive power should render it of special value.

Emulsions

A further suggested use is in the preparation of emulsions of various types. It is stated that a small amount of bentonite acts both as an accelerator and as a stabilizer in emulsions made up of water and various oils, fats and resins. It is believed that this field has not been very actively investigated; but it presents great possibilities and opportunities for research.

A further extension of this field is the emulsifying of asphalt, coal tar residues and pitch. It is stated that bentonite emulsions of such substances give results in service superior to the straight substances themselves, and the roofing industry may be cited as a field offering considerable possibilities. It is believed that bentonite has been used with decided success in the production of asphalt emulsions for roofing purposes. Interesting results have recently been obtained in the Mines Branch laboratories by the use of bentonite in grinding asphalt for the preparation of asphaltic waterproofing compounds.¹ The work was undertaken for a firm desirous of making such a compound for the waterproofing of paper board, and very satisfactory products were obtained by grinding asphalt-bentonite-water mixtures without heating of the mass. Equally good results were also secured in the preparation of rosin-bentonite products. The tests made suggest that bentonite may serve a useful purpose in facilitating the grinding of materials that are sticky or tacky at ordinary temperatures and have a tendency to ball during grinding.

Among the further possibilities offered by bentonite along related lines, is its suggested use in extracting the asphalt content of the so-called "tar sands." The problem of profitably extracting the asphalt from such sands occurring in the McMurray district of northern Alberta has been the subject of extended research, and it has recently been found that bentonite can be employed successfully to assist recovery.

Explosives

Bentonite has been proposed as an absorbent of nitro-glycerine in the manufacture of dynamite. It is reported to possess twice the absorbent power of diatomaceous earth.

Fertilizers

On account of its property of adsorbing ions from salt solutions, notably those of the alkalis, bentonite suggests itself as a fertilizer filler material. Commercial mixed fertilizers commonly contain a percentage of comparatively inactive filler, which is added to balance the formula. Such fillers add little direct plant food value to the goods, although some substances as marl, peat, and certain industrial wastes may be valuable indirectly, by slowly yielding available plant food or for improving soil

¹The results of these tests have appeared in the following technical journals: Chem. Met. Eng., 30, 986, June 23, 1924; Can. Min. Journ., May 2, 1924, 431; Eng. Min. Journ. Press, 118, 136, July 26, 1924.

conditions. Clay soils are commonly more fertile than sandy soils, from several causes. One of the chief reasons is that clay particles have the property of effecting base exchange between themselves and the salt solutions derived from the decomposition of mineral particles in the soil, and thus prevent the removal of valuable plant food by leaching. The same exchange takes place between the clay colloids and the solution of the fertilizer salts applied to the soil. Liming of the soil effects the exchange in a reverse direction, the calcium being taken up (adsorbed) by the colloids and the adsorbed bases released and rendered available as plant food. It is to be noted that this exchange is not a chemical interchange of acid radicals, but is regarded as in the nature of ionic change induced by mass action.

The addition of bentonite to soils, particularly to light soils, through the medium of fertilizer plus bentonite filler, would probably be of decided advantage.

As a Filler or Loader

Fillers are those inert, powdered substances—usually minerals or artificially prepared chemical compounds—which are introduced into many manufactured products to give weight or body to the goods. In the case of textiles and similar materials, paper, etc., the loader is added in the form of a liquid suspension, or size, in order to get it thoroughly into the fabric, and the addition is made after the body is complete and merely serves to fill up the pores or mesh. In the great majority of products, however, the filler forms an integral part of the finished article (*e.g.* paint, rubber, moulded composition products of various kinds) and is incorporated into the batch during manufacture. Fillers being inert substances do not enter into chemical combination with the other ingredients used, either solids or liquids. Their physical properties may materially modify the finished product, particularly the fineness of grain, which generally is of prime importance. It is obvious that the finer a material is—that is, the greater the number of particles into which it is divided—the more homogeneous will be the product made from it. In ordinary practice, a fineness of up to 200 mesh is commonly stipulated for filler materials, and for special purposes even as high as 350 mesh may be specified. This does not mean that such fineness is by any means the desirable limit, but beyond that it is hardly possible to go, owing to the limitations imposed by even the most modern grinding and screening equipment. The new development of the colloidal mill will, perhaps, result in making available, filler powders of a degree of fineness hitherto thought impossible.

In bentonite, however, we have that desirable product, a chemically inert filler whose particles are already of a degree of fineness far beyond that attainable by even the most elaborate grinding machines, and in addition possesses certain physical properties—such as, for example, high absorptive power for liquids and adsorptive power for various chemical compounds, such as dyes and colours; ability to form permanent suspensions in dispersion media, or stable mineral gels—that, in some cases at least, may render the material of decided value.

The field for bentonite as a filling or loading substance may be regarded, however, as of secondary importance compared with that offered by its use as a direct agent or co-agent, as indicated in the list of other suggested possible uses enumerated here. As a filler, bentonite at the

present moment is generally regarded merely as a substitute for other products now used, rather than as something entirely different; and since many of these other products are low-priced, the objection of cost is one that is immediately raised and helps to lessen the interest in bentonite. A further disadvantage under which bentonite has been placed as a filler material is that only impure or unrefined clay is available as sample material, and objection is often taken to it because of its gritty impurities. Few industries are prepared to undertake the refining of the materials used in their plants, and until refined bentonite is offered to the trade, little active interest is likely to be expressed in it.

The new development of sprayed rubber suggests the possibility of securing rubber-bentonite emulsions, and the attaining of thoroughly homogeneous rubber-bentonite bodies by means of spray mixing.

Foundry Work

Bentonite finds successful application as an ingredient of core washes, in which, as a clay gel, it functions to keep the carbonaceous ingredients of the wash in suspension. A further use that suggests itself is as a bonding agent in moulding sands, more especially the high silica sands used in steel foundry practice.

Horticultural Sprays and Animal Dips

The extremely sticky nature of bentonite-water mixtures, its ability to form permanent dispersions, and its inert character, all suggest that bentonite may be of value as a sticking or spreading agent in insecticidal sprays and dusts. Special spreaders for use in such sprays are on the market, and in at least one instance, the spreading medium is believed to be bentonite.

For cattle dips, bentonite might prove of value to increase the wetting power of the dipping fluid. For this purpose, it could possibly replace soap, which now forms an ingredient of certain official dips.

Lubricants

It has been suggested that there may be some field for bentonite in lubricants, where its inert character, excessive smoothness, and property of remaining indefinitely in suspension in a liquid medium, would make it of value.

Paints

For oil paints, the possibilities of bentonite are discussed under the heading of "Fillers," but it may be again stated that an inert substance capable of forming stable suspensions in liquid media, as well as having properties that suggest its exceptional suitability as a base for lake colours may well have extended application in the paint trade.

For cold water paints, distempers, or calsumines, the field would appear to be even broader.

Paste, Glue and Size

The excessively sticky nature of bentonite when mixed with water at once suggests that it may have valuable adhesive properties. This does not seem to be borne out in actual practice, for though bentonite gel adheres readily to most surfaces, it is much inferior in this respect to most

of the substances commonly used in adhesives. Bentonite gel, by itself, cannot be regarded as having any particular value as an adhesive paste or glue, though it is believed to have been used with some success as a minor ingredient of such compounds. In this case, the bentonite probably functioned as a colloidal co-agent, rather than directly as an adhesive.

As a sizing agent, particularly for cotton yarn or fabrics, and for textiles generally, cordage, etc., bentonite has been shown to have valuable possibilities, adhering well to the material and imparting no harshness to the finished goods. In addition, its inorganic nature renders materials sized with it less subject to attack by mould than those sized with starch.

Pencils, Crayons and Inks

In the pencil and crayon trade, bentonite will probably be found valuable in place of the clay ordinarily used. It is believed that some prominent pencil firms are already employing bentonite, more particularly for crayon work and indelible leads. In pencil manufacture, the clay for the leads has to undergo very prolonged grinding in order to eliminate all trace of grit; or else, in the case of some of the exceedingly plastic ball and stoneware clays, is subjected to a costly refining process by endosmotic means. A properly cleaned bentonite, consisting wholly of colloidal clay, would enable grinding to be dispensed with and would naturally yield a superior product. In making up the graphite-bentonite mix for ordinary black lead pencils, some other medium than water would probably have to be used, owing to the excessive shrinkage of bentonite on drying. For crayons, indelible leads, pastel colours, etc., which are compounded with grease or wax, bentonite should prove of great value. In printers' inks, which also require an excessively fine clay, bentonite should prove most useful.

Pharmaceuticals and Cosmetics

The possibilities of the colloidal clays in this broad field have attained considerable development in recent years. One of the earliest uses to which the western bentonites were put was as hoof packing for horses, the clay being found very efficacious for relieving sore or inflamed hoofs. Bentonite has long been used for this purpose in the western United States under the name of "Denver Mud." Bentonite is also believed to have originally been the base for antiphlogistine, though it has now apparently been supplanted by kaolin for this purpose. The efficacy of certain clays, either kaolin or more particularly the colloidal, bentonitic types, in the treatment of a number of bodily disorders, such as ailments of the scrofulous and eczematous type, abscesses, rheumatic and pulmonary affections, as well as for cleansing and healing sores and wounds, is claimed to have been established, though it is not known that any systematic investigation of this question has ever been conducted on strict medical lines. Prepared colloidal silica has recently been shown to possess valuable curative and antiseptic properties in the treatment of wounds; and the beneficial effects claimed for bentonite are quite probably based on something more than mere imagination.

Bentonite is also the base used in many of the numerous facial clay packs and so-called beauty clays placed on the market during the last couple of years, as well as in various toilet creams, cosmetics and special soaps.

For all of the above purposes, the observed beneficial effects are ascribed, in part at least, to the great "drawing" power of the clay, due to its high water absorption; the clay absorbing moisture from the skin or tissue, draws with it the dissolved salts or other impurities responsible for morbid conditions. As a toilet or dusting powder, bentonite is indicated as of value as an absorbent of perspiration and associated body excretions.

Bentonite is stated to have been used as a diluent of certain powerful drugs sold in powder form.

Pulp and Paper

One of the most important fields in which progress has been made in the use of bentonite is the paper industry, though even here the present application is small.

Results of work conducted at the Forest Products Laboratory of the United States Department of Agriculture have demonstrated that bentonite can be successfully used to remove particles of carbon black from paper stock in the de-inking of old newsprint. The bentonite plays no part in the actual dissociation of the carbon black from the paper, which is effected by an alkali, but serves to carry off the carbon particles during the subsequent washing of the paper stock and to prevent their retention in the fibres of the paper. Bentonite has been successfully used for the above purpose in actual practice on an industrial scale.

It has also been demonstrated, at the instance of the Forest Products Laboratory, that bentonite is very efficient in promoting the retention of china clay used as a loader in the manufacture of paper. In commercial tests, the addition of a small amount of bentonite resulted in a material increase in retention, and at the same time improved the quality of the paper.

It is stated that bentonite successfully overcomes the gumming of the screens used in the pulp industry, the clay presumably forming an emulsion with the resinous matter.

As a straight paper filler or loader, bentonite is reported to have been used in large quantities by a Denver mill, most of the early production from Wyoming having been used for this purpose.

Refining of Oils and Fats

The possibilities of clays of bentonite type have attracted much attention from the petroleum industry in the last two or three years, and important advances have been made in its use in the contact process of refining and clarifying petroleum products.

Most of the work along these lines has been carried out by the Pacific Coast refineries, and it has been shown that such clays can be very successfully used for cleaning heavy lubricating oils, kerosene and gasoline. In the case of lubricating oils, the clay may be employed to treat either the raw products, or the acid-treated oils. With kerosene, the refining with clay usually follows acid treatment of the oil; gasoline is generally clay-treated without preliminary acid treatment. The clay most commonly used so far is a California product, obtained either from the Barstow region or from Otay, south of San Diego. The Barstow (so-called "Death Valley") clay differs considerably in its physical character from the Otay material, being less colloidal and more generally resembling kaolin. These

clays have to undergo certain acid treatment in order to give maximum efficiency in the clarifying of oils. This treatment consists in adding sulphuric acid (50 per cent by weight of 66° acid) to the powdered clay and heating the mixture by live steam. The acidulated clay is afterwards washed, to remove the surplus acid and soluble salts, and is then ready to be employed for oil refining. To effect this, the slurry is led into an agitating system, into which are also introduced the oil and steam. After thorough agitation, the oil-clay mixture proceeds to a storage tank, from which it is drawn off to a filter press, which removes the clay and passes out clean oil. The temperature during treatment ranges from 240°-300° F., depending on the class of oil to be cleaned. Some light distillates can be cleaned in the cold, but the heavy oils all require heat treatment. The efficiency of the acid-treated clays in the contact process is very much higher than that of fuller's earth. The amount of clay required ranges from as low as 1 pound per barrel of oil in the case of gasoline, to 100 pounds per barrel for the dark, heavy lubricating oils.

The manufacture as well as the use of acid-treated clays for oil refining is covered by a number of patents, and the contact process of refining by means of such clays is employed by various companies on a royalty basis.

There should be an immediate opening for the use of acid-treated bentonite by Canadian oil refineries in the west and mid-west; provided, of course, that Canadian bentonite can successfully undergo such treatment, which there seems no reason to doubt, although it is not known that any research along these lines has been conducted. The Mines Branch has, however, recently supplied samples of Canadian bentonite to several of the Californian oil companies, and these have indicated their intention of making tests on the clay. In view of the fact that Canada produces no fuller's earth, and has, consequently, to import all such earth at present used by domestic oil refineries; and considering the higher efficiency of acid-treated clay for the refining of petroleum products, the attention of Canadian oil refineries might be profitably directed to the substitution of treated bentonite for fuller's earth.

In addition to the possibilities offered by the petroleum industry, there naturally suggests itself a further field for acid-treated bentonite in the clarifying and bleaching of vegetable and animal oils and fats. Tests carried out in the Mines Branch laboratories by E. A. Thompson and A. Sadler have shown that Canadian bentonite, after treatment with either hydrochloric or sulphuric acid, exercised a much superior bleaching effect upon a crude, brown packing-house lard ("soap grease") than either standard American or English fuller's earth.

As illustrating the adsorptive power of bentonite, a piece of the crude clay immersed in ordinary commercial (refined) kerosene was found after the lapse of some months to have turned a deep terra cotta colour.

Putty

As a prime ingredient of putty, bentonite might prove an efficient substitute for whiting; though here the relative cost of the two materials would hardly permit of bentonite being used in general practice. The relative oil absorption of the two materials would need to be determined and taken into consideration in this connection.

Soaps and Detergent Preparations

Research has shown that colloidal clays possess valuable detergent properties and may be used to good advantage in soaps, scouring compounds and cleansers of various kinds. While this is a modern development, it is not by any means an original use, since bentonite has long gone by the name of "soap clay" in the North West, and early reports of the Geological Survey of Canada show that it was commonly used at the Hudson Bay posts for washing blankets and woollens. Bentonite, therefore, is to be regarded not merely as of use as an inert filler or loader in cake soaps, but as an active ingredient performing useful detergent service. It is claimed that bentonite can actually replace from 25 to 50 per cent of the soap substance in hard and soft soaps, the product being equal, if not superior, to straight soap.

In the scouring of textiles, particularly, it is claimed that bentonite has proved its merit, having a superior bottoming effect on yarns and fabrics, producing more brilliant colour in dyed materials, as well as increased clarity and sharpness of print goods, and putting on all goods a finish unequalled by ordinary scouring agents. Under the trade names "Mulsoid," "Lanoid," "Loftine," etc., bentonite detergents are already on the British market. It is probable that the clay will ultimately be used in a much wider range of similar products.

Stove Polish

Bentonite has been used as the bonding agent in cake or paste stove polishes, where it materially cuts down the amount of clay required to produce the same bulk of polish.

As a Suspending Agent

The use of bentonite as a suspending agent in enamel mixtures has already been referred to under Ceramics. Its successful application in this connection suggests a wide field of usefulness for it in the suspending of various solids in liquid media of suitable character—that is, in liquids containing no electrolyte that will flocculate the clay.

Water Softening

The property possessed by bentonite of effecting base exchange, that is, of selectively adsorbing ions from salt solutions, has been utilized in the manufacture of water softeners. Two of the best known water softeners on the American market that act on this principle have employed South Dakota bentonite as raw material. Briefly, the process consists in converting the clay into granules, heating to destroy its colloidal character, and then re-hydrating with a dilute solution of an alkali. On passing water containing calcium or magnesium salts through the product, ionic base exchange takes place, the calcium or magnesium being adsorbed and the alkali freed to combine with the acid radical of the original salts. The product may be regenerated by passing through it a brine solution, whereupon the reverse action takes place, the calcium or magnesium being released to form soluble chlorides, which are removed by washing.

As a Wetting Agent

In Technical Paper No. 262 of the U.S. Bureau of Mines, p. 51, the use of soap-water sprays is advocated for dust-laying purposes in coal mines. Bentonite suggests itself as a substitute for soap for this purpose.]

PATENTS COVERING THE USE OF BENTONITE

BRITISH

- No. 197,012, Feb. 3, 1922, C. J. Coleman. Bentonite in cleaning and polishing preparations.
 No. 203,720, Mar. 8, 1922, J. F. Moseley. Bentonite in scouring and detergent preparations.

UNITED STATES

- No. 1,286,043, Nov. 26, 1918, L. McCulloch. Heat insulating material consisting of mica flakes cemented by a bentonite paste.
 No. 1,421,195, Jan. 27, 1922, H. R. Eyrich. Process for de-inking paper by the use of bentonite.
 No. 1,434,133, Oct. 31, 1922, T. G. McDougal. Refractory material containing 5 per cent of bentonite.
 No. 1,435,972, Nov. 21, 1922, Z. Olsson. Refining agent for vegetable and other oils, composed of bauxite, starch and bentonite.
 No. 1,442,413, Jan. 16, 1923, Z. Olsson. Refractory material composed of 95 per cent of bauxite and 5 per cent of bentonite.
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APPENDIX

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Character, Properties and Uses of Colloidal Clays

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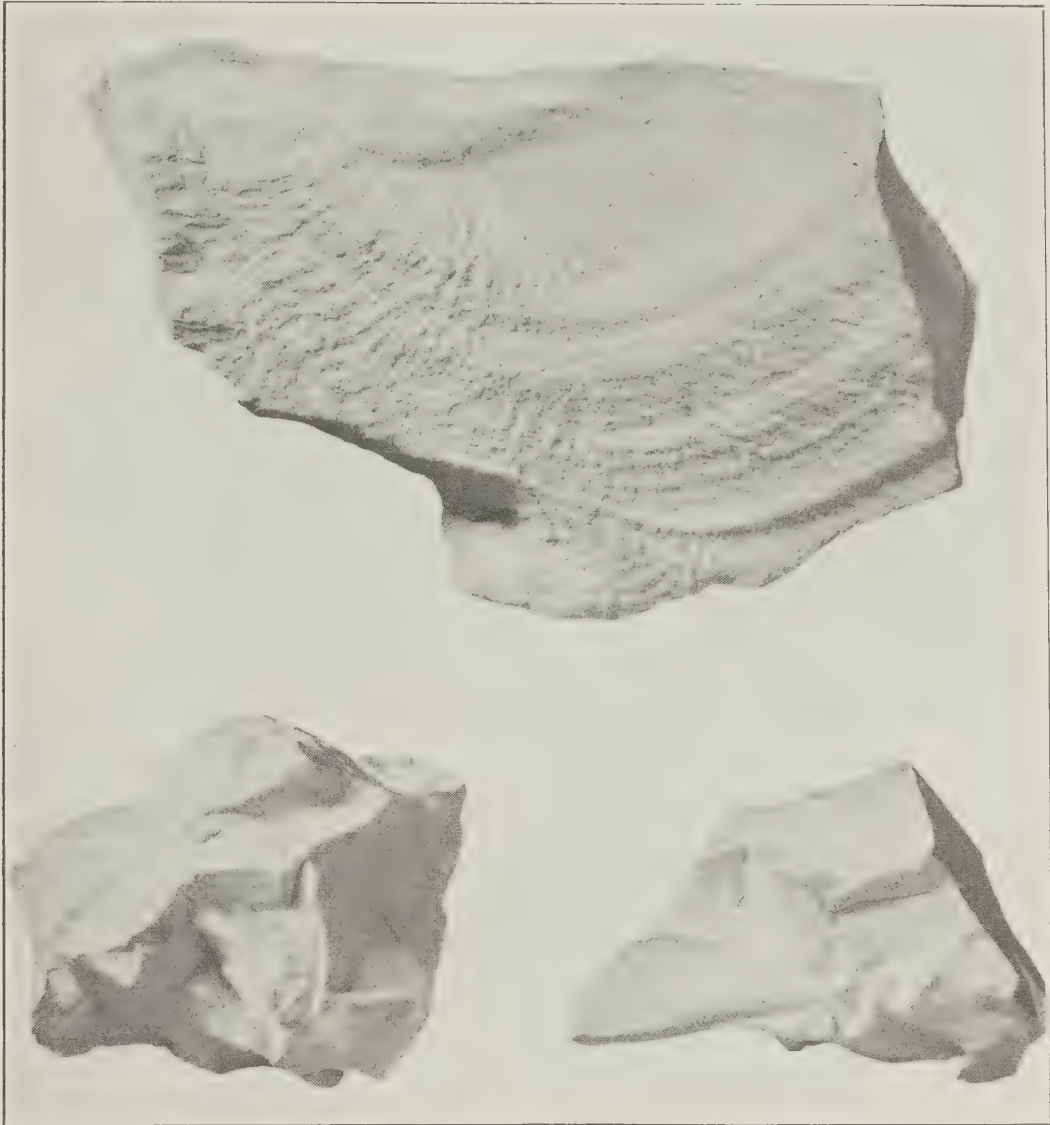
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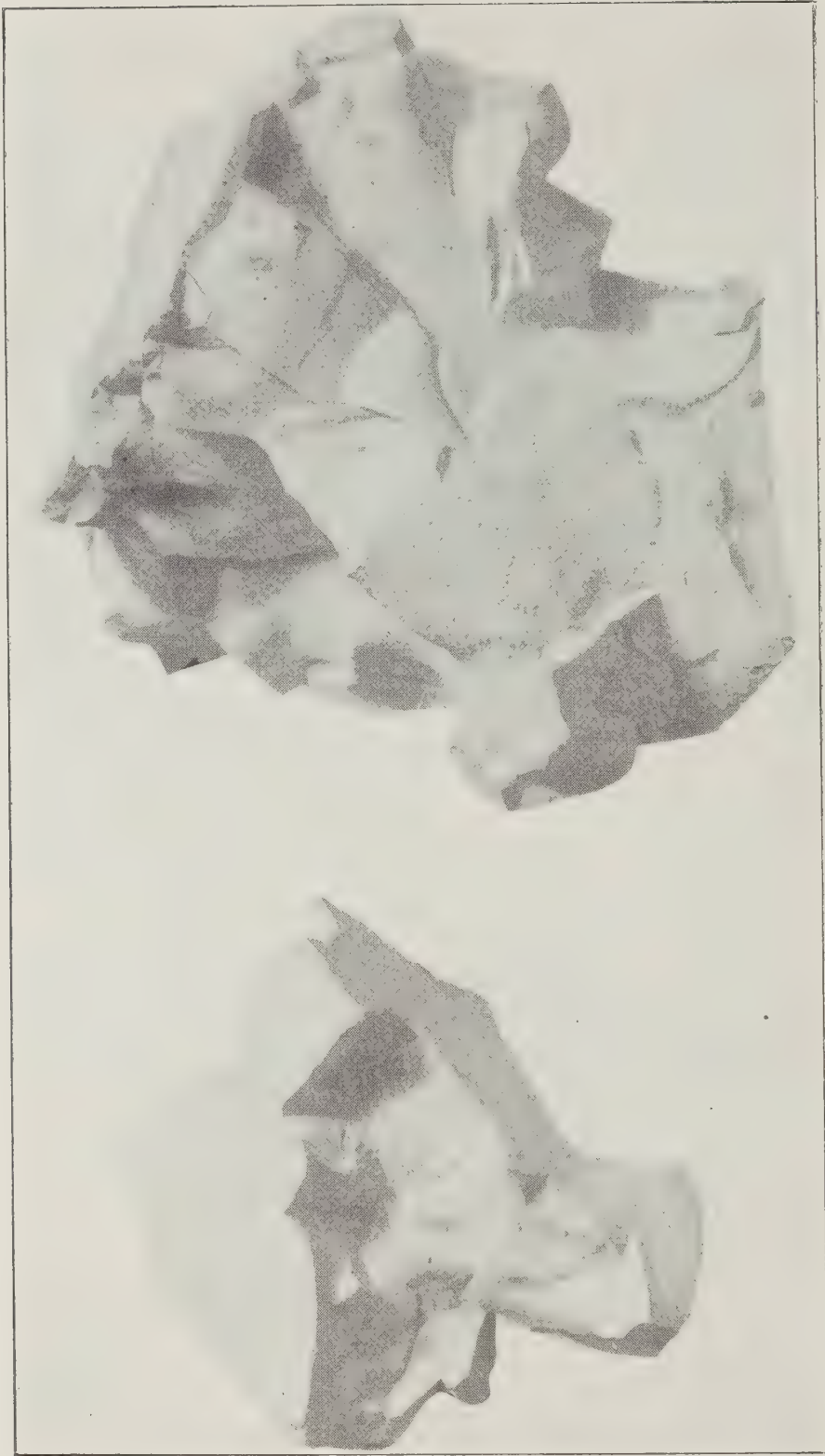
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PLATE I

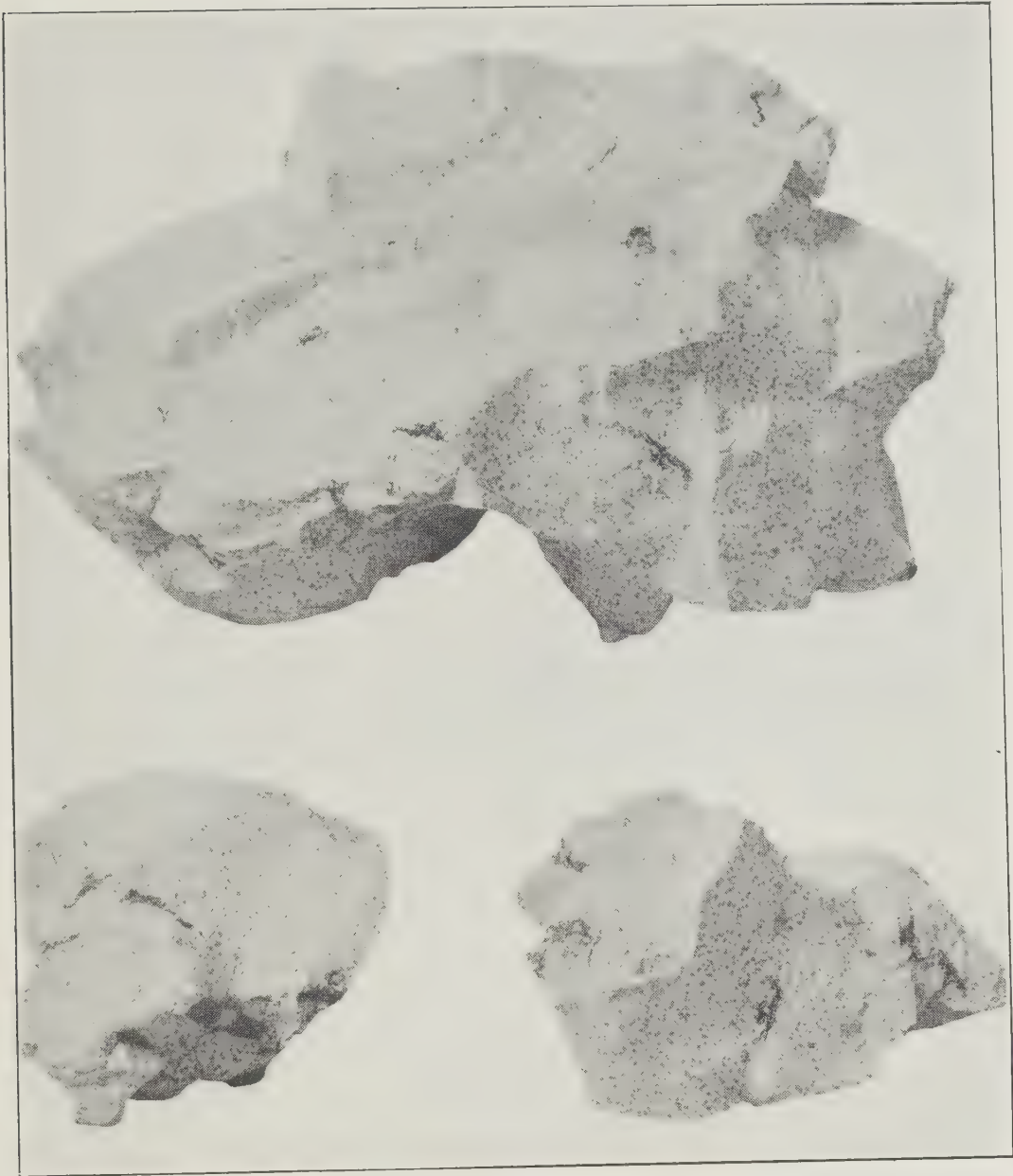


Bentonite from Newcastle, Wyoming. The type Wyoming bentonite has a softer and more earthy texture than that from British Columbia and Alberta, shown in Plates II and III. It is variously shaly or massive and has a pale yellow colour when dry.



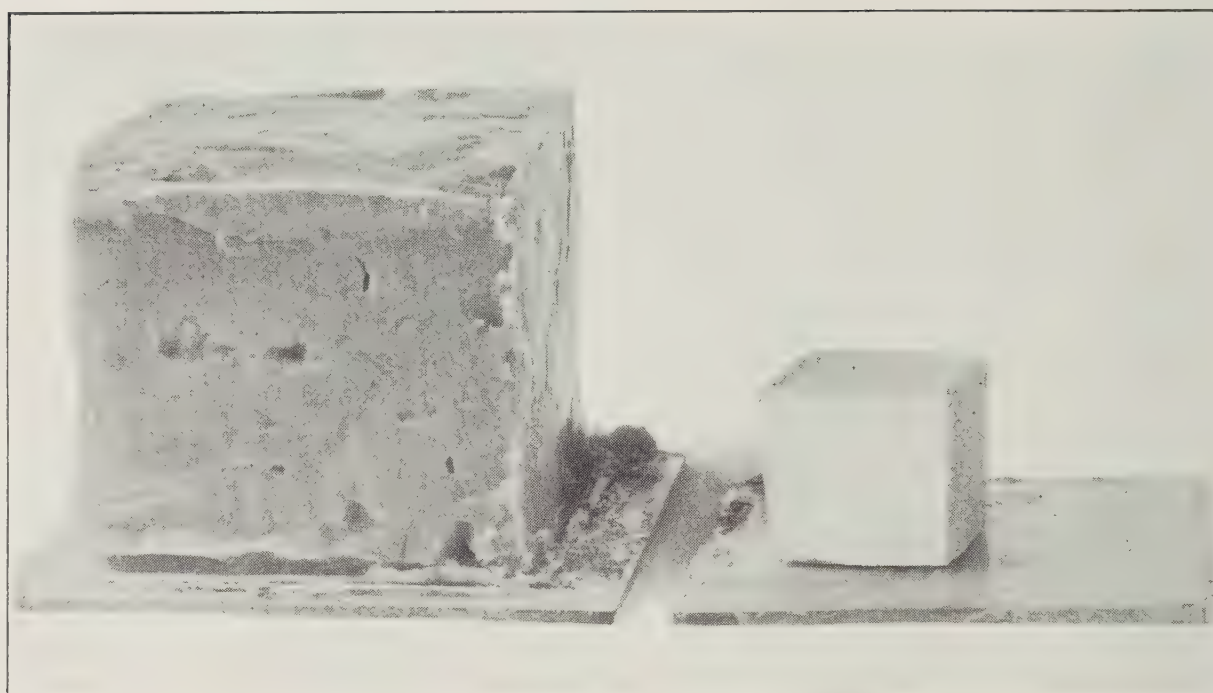
Bentonite from Quilchena, B.C. This clay is extremely dense and hard and breaks out in large blocks with conchoidal fracture and sharp edges. It dries out to a pale cream shade.

PLATE III



Bentonite from mine of the Rosedale Coal Company, Rosedale, Alberta. This clay forms a thin parting between two coal seams. It is hard and dense, has a drab, grey colour and contains carbonaceous material. In colloidal character, it compares well with the Wyoming bentonite.

PLATE IV



Illustrates the swelling property of bentonite. The small cube was cut from a piece of dry bentonite; the large cube represents the same after taking up all the water it would hold and still retain its form. The volume of the large cube is 13·8 times that of the small cube.

PLATE V



Outcrop of bentonite bed at Clay Spur, near Newcastle, Wyoming. The deposit is flat-lying and has little or no overburden. The photograph shows the bed partly broken up and the clay stock-piled. The peculiar weathering crust exhibited by bentonite is shown.

PLATE VI



Bentonite bed forming surface of the ground at Clay Spur, near Newcastle, Wyoming. Note the characteristic weathering surface and almost complete absence of vegetation.

PLATE VII



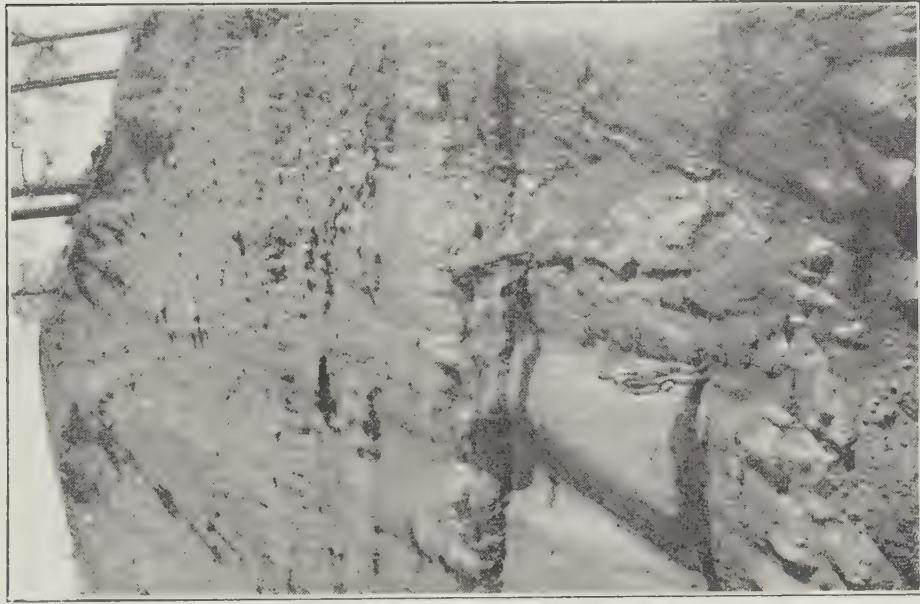
Bentonite bed, S. $\frac{1}{2}$, S. 17, T. 6, R. 22, W. 3, south side of Frenchman River valley, Cypress hills, Saskatchewan. The bentonite bed is 8 feet thick and is the dark band immediately overlying the heavy white clay (Whitemud beds).

PLATE VIII



Bentonite bed, 5 feet thick, overlying heavy bedded volcanic ash, S. 2, T. 6, R. 29, W. 3, near St. Victor, Saskatchewan. The bentonite is the dark band forming the surface of the bluff: it is associated with thin lignite seams. A second 3-foot bentonite bed occurs above the one shown and separated from it by 12 feet of ash. This upper bed does not appear in the photograph.

PLATE IX



Outcrop of 14-foot bentonite bed in railway cut at Princeton, B.C. The bed dips 20 degrees into the bank, and is well situated for development. The clay could be dumped direct into railroad cars.

PLATE X



Bed of bentonite, 8 feet thick, overlying coal seam, on Guichon ranch, Quilchena, nine miles east of Nicola, B.C. The bed dips 30 degrees into the hill, and consists of massive, cream-coloured bentonite that breaks out in large lumps with conchoidal fracture.

PLATE XI



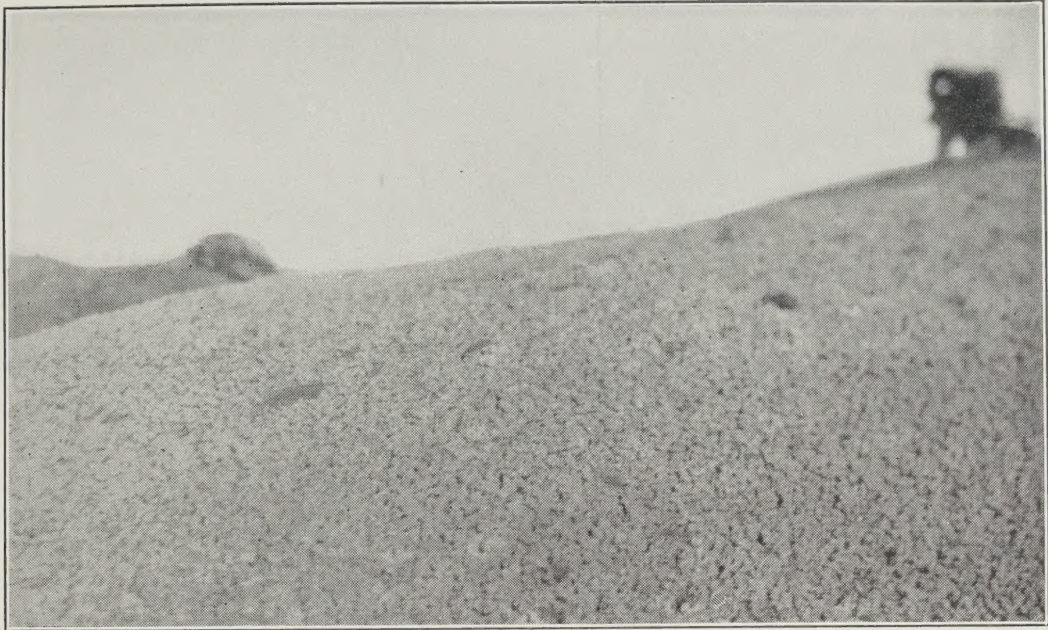
Typical small butte in Red Deer valley, near Drumheller, Alberta. A bed of bentonite, 3 feet thick, occurs just below the light-coloured band half way up the slope. Thin bentonite beds occur similarly in many of the buttes up and down the valley and in the cliffs forming its sides.

PLATE XII



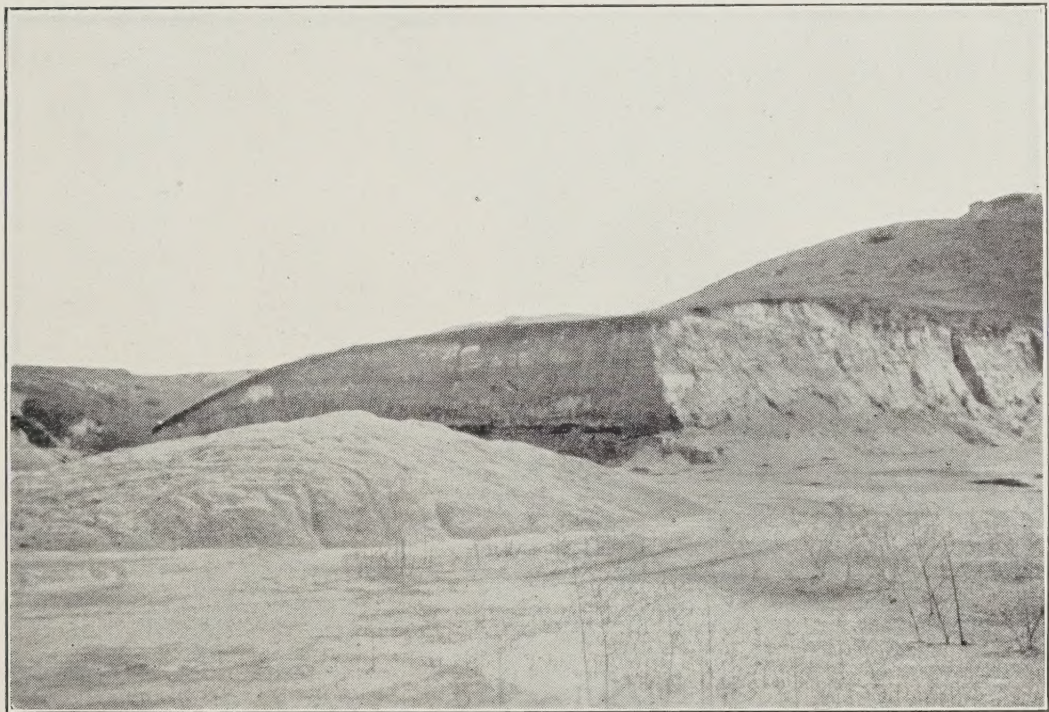
Near view of the bentonite outcrop shown in Plate XI. Bentonite beds commonly form the caps of small terraces around the flanks of buttes and side-hill projections in the Red Deer valley, the clay protecting the lower beds from erosion.

PLATE XIII



Near view of the bentonite bed shown in Plate XII, showing characteristic weathering surface of bentonite. Both the shaly and massive types of bentonite exhibit this characteristic feature

PLATE XIV



Bentonite-like clay (otaylite), possibly a sub-variety of montmorillonite or leverrierite, near Otay, south of San Diego, California. The clay forms a bed, 5 feet thick, at the base of the bank, and is overlain by sand. It is, variously, pink, white and brown, and is used for oil refining. Stock pile in the middle foreground.

